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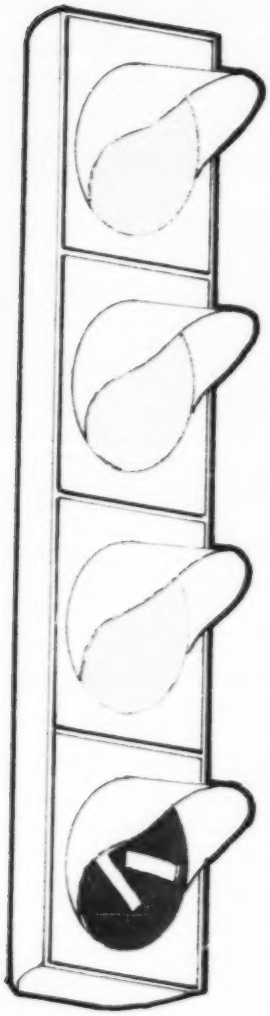

TRAFFIC SIGNALS

Left Turn Phasing, Timing and Displays

Vehicle Clearance Intervals

RECOMMENDED PRACTICE

PREPARED FOR THE
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TRAFFIC SIGNALS - LEFT-TURN PHASING, TIMING AND DISPLAYS VEHICLE CLEARANCE INTERVALS - RECOMMENDED PRACTICE

by
Keith G. Mclean
Chief Traffic Engineer
DeLCan (De Leuw Cather, Canada Ltd.)

March 1987

The contents of this report reflect the views of the authors and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

This report does not constitute a standard, specification, or regulation.

Un rapport sommaire de ce document est disponible en français sous le titre: "Programmation des feux de virage à gauche prioritaire-pratiques recommandées", TP8326F.

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ACKNOWLEDGEMENTS

This study was made possible by the cooperation of the Transportation Development Centre, Transport Canada and representatives of a number of public agencies that actively assisted in the research and development of the guidelines which are proposed in this report. The assistance was provided by the members of the Council on Uniform Traffic Control Devices for Canada, Technical and Research Committee Study Group for this project whose names appear on the page opposite. As well the assistance of:

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is gratefully acknowledged.

This study was sponsored by the Energy Research and Development Program of Energy Mines and Resources, Canada.

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Transports Canada / Transport Canada

Développement / Development

FORMULE DOCUMENTAIRE DU RAPPORT

1. N° du rapport Transports Canada	2. N° de l'étude — CDT	3. N° de catalogue du destinataire
TP 8226E	6358	

4. Titre et sous-titre	5. Date du rapport
Traffic Signals - Left-Turn Phasing, Timing and Displays, Vehicle Clearance Intervals - Recommended Practice	Mars 1987
	6. N° du rapport de l'organisme exécutant: 04-1442A-00
7. Auteur(s): K.G. McLean (P.Eng.) et al	8. N° de dossier Transports Canada: D1465-452
9. Nom et adresse de l'organisme exécutant: DeLeuw Cather Canada Ltd. 2315 Riverside Drive Billings Bridge Plaza, P.O. Box 8004 Ottawa (Ontario) K1G 3H6	10. N° de dossier — ASC
	11. N° de contrat — ASC ou Transports Canada: OSD84-00312
12. Nom et adresse de l'organisme parrain: Centre de développement des transports (CDT) 200 ouest boul. Dorchester Suite 601, tour ouest Montréal (Québec) H2Z 1X4	13. Genre de rapport et période visée: Rapport Final 03/85-03/87
	14. Code de l'organisme parrain: CDT 6358
15. Remarques additionnelles: Parrainé par le programme de R&D énergétique d'Energie, Mines et Ressources Canada	16. Agent de projet — CDT: C. Hirou, L. Suen

17. Résumé

Le présent rapport donne le résultat de l'évaluation qui a été faite des interviews et des questionnaires auxquels ont répondu les ingénieurs du trafic urbain, un peu partout au Canada, en ce qui concerne les normes applicables aux feux de virage à gauche, à la signalisation correspondante et à la programmation.

De plus, ce rapport formule diverses recommandations destinées à guider le Conseil canadien de normalisation des dispositifs de régulation de la circulation dans la mise en oeuvre des méthodes et des dispositifs applicables.

Voir aussi le rapport "Traffic Signals - Left-Turn Phasing and Displays, Vehicle Clearance Intervals, Flashing Operation - State-of-the-Art", DeLeuw Cather Canada Ltd, 1984, TP 5324E.

18. Mots-clés	19. Diffusion
Signalisation, feux de virage à gauche, programmation.	Disponible sur demande auprès du Centre de développement des transports.

20. Classification de sécurité (de ce rapport)	21. Classification de sécurité (de cette page)	22. Nombre de pages	23. Prix
Non classifié	Non classifiée	25 + App.	

Transport Canada / Transports Canada

Development / Développement

REPORT DOCUMENTATION FORM

1. Transport Canada Report No.	2. TDC Project No.	3. Recipient's Catalogue No.
TP 8226E	6358	

4. Title and Subtitle	5. Report Date
Traffic Signals - Left-Turn Phasing, Timing and Displays, Vehicle Clearance Intervals - Recommended Practice	March 1987
	6. Performing Organization Report No. 04-1442A-00
7. Author(s) K.G. McLean (P.Eng.) et al	8. Transport Canada File No. D1465-452
9. Performing Organization Name and Address DeLeuw Cather Canada Ltd. 2315 Riverside Drive Billings Bridge Plaza, P.O. Box 8004 Ottawa, Ontario K1G 3H6	10. DSS File No.
	11. DSS or Transport Canada Contract No. OSD84-00312
12. Sponsoring Agency Name and Address Transportation Development Centre (TDC) 200 Dorchester Blvd. West Suite 601, West Tower Montreal, Quebec H2Z 1X4	13. Type of Report and Period Covered Final 03/85 - 03/87
	14. Sponsoring Agency Code TDC 6358
15. Supplementary Notes Sponsored by the Energy R&D Program of Energy, Mines and Resources Canada	16. TDC Project Officer C. Hirou, L. Suen

17. Abstract

This report provides the results of an evaluation of responses to a series of questionnaires and of meetings with practicing traffic engineers across Canada with respect to the timing and phasing of traffic signals, including vehicle clearance intervals, as well as the signal head displays that are associated with the various left-turn phasing alternatives.

The report provides recommendations to assist the Canadian Council on Uniform Traffic Control Devices in the development of uniform standards for the application of practices and devices in the foregoing aspects of the use of traffic signals.

See also report TP 5324E "Traffic Signals - Left-Turn Phasing and Displays, Vehicle Clearance Intervals, Flashing Operation - State-of-the-Art", DeLeuw Cather Canada Ltd., 1984.

18. Key Words	19. Distribution Statement
Traffic Signals, Left-Turn Phasing, Vehicle Clearance Intervals	Available upon request from Transportation Development Centre.

20. Security Classification (of this report)	21. Security Classification (of this page)	22. No. of Pages	23. Price
Unclassified	Unclassified	25 + App.	Nil

Canada

SUMMARY

This is the second phase of a project, the first phase of which was completed in March 1984 with the publishing of the report entitled "Traffic Signals - Left-Turn Phasing and Displays, Vehicle Clearance Intervals, Flashing Operation - State-of-the-Art" (Transportation Development Centre TP 5324E).

In March 1985, DeLCan was authorized to undertake the project which had as its objectives:

- the development of standard practices to be used in the determination of vehicle clearance intervals and the need for and timing of left-turn phases in the operation of traffic signals;

- the development of standardized configurations for traffic signal indications to be used to control left-turn movements at traffic signal controlled intersections.

The project has met its objective of producing a recommended practice for:

- determining the need for a left-turn phase in a traffic signal phasing sequence and the period of operation;

- the timing of left-turn phases;

- the timing of clearance intervals;

- the traffic signal indications that should be displayed for each of the left-turn phasing alternatives.

Traffic signal indications are illustrated for traffic signal heads which govern "left-turn lanes" and "other than left-turn lanes" as well as for traffic signal heads "shared" by motorists in all lanes. No attempt was made to define the circumstances under which these "shared" signal heads should be used or where traffic signal heads should be placed in circumstances where such traffic signal heads would govern specific lanes. A project, entitled "Uniform Traffic Signal Display" (Project Number 158), under the auspices of the Council on Uniform Traffic Control Devices for Canada, Technical and Research Committee is addressing the requirements in this regard. There are, however, cases where signal indications for some of the phasing alternatives should only be used where left-turn lanes are available. The exhibits for these phasing alternatives do not include proposals for "shared" signal heads.

Exhibits 1 to 9 in Annex 2 of the report illustrate the traffic signal indications proposed for the nine basic phasing alternatives, as follows:

(a) Alternatives in which there may be "shared" traffic signal indications:

PROTECTED/PERMISSIVE
- Advanced Green

PERMISSIVE/PROTECTED
- Extended Green

PROTECTED/PERMISSIVE
- Leading Simultaneous Left Turn

PERMISSIVE/PROTECTED
- Lagging Simultaneous Left Turn

(b) Alternatives in which there should be no "shared" traffic signal indications:

EXCLUSIVE PROTECTED
- Leading Exclusive Protected Left Turn
- Lagging Exclusive Protected Left Turn
- Advanced Exclusive Protected Left Turn
- Extended Exclusive Protected Left Turn

(c) An infrequently used phasing alternative in which there may be "shared" traffic signal indications:

SEPARATE PROTECTED LEFT TURN.

The recommended practices should be considered by the Technical and Research Committee of the Council on Uniform Traffic Control Devices for Canada for inclusion in the Manual of Uniform Traffic Control Devices for Canada.

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APPENDIX B	RESPONSES TO THE QUESTIONNAIRE
APPENDIX C	ISSUES ARISING FROM THE RESPONSES TO THE QUESTIONNAIRE
APPENDIX D	MINUTES OF MEETING OF SEPTEMBER 30, 1985
APPENDIX E	MATRIX, COMMENTS AND EXPLANATORY NOTES RELATED TO - ISSUES RELATED TO THE BASIS FOR DETERMINING THE NEED FOR A LEFT-TURN PHASE - ISSUES RELATED TO THE BASIS FOR TIMING LEFT-TURN PHASES - ISSUES RELATED TO THE TIMING OF CLEARANCE INTERVALS FOR NORMAL THROUGH MOVEMENTS
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APPENDIX K	SKETCHES OF MOST COMMON INTERSECTION CONFIGURATIONS FOR UNDIVIDED AND DIVIDED INTERSECTION APPROACHES
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EXHIBIT 2 TRAFFIC SIGNAL INDICATIONS FOR - PERMISSIVE/PROTECTED EXTENDED - LEFT-TURN PHASING

EXHIBIT 3 TRAFFIC SIGNAL INDICATIONS FOR - PROTECTED/PERMISSIVE LEADING SIMULTANEOUS - LEFT-TURN PHASING

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1.0 INTRODUCTION

This is the second phase of a project which had, as its initiation, the importance placed on the following subject area by the Roads and Transportation Association of Canada Traffic Operations Management Committee and its Traffic Operations Technical Committee:

- standardization of signal displays and phasing;
- vehicle clearance intervals;
- left-turn phasing and capacity;
- standardization of left-turn movement traffic signal indicators.

These areas of concern were felt to be in a group representing the highest priority, from a list compiled by the Roads and Transportation Association of Canada, of those areas in need of Research and Development.

The first phase of the project was completed in March 1984 with the publishing of the report entitled "Traffic Signals - Left-Turn Phasing and Displays, Vehicle Clearance Intervals, Flashing Operation, State-of-the-Art".

In March 1985, DeLCan was authorized to undertake the project entitled "Preparation of Standards for Traffic Signal Operations and Applications Aimed at Conserving Energy through Effective Traffic Management" and propose a recommended practice for:

- determining the need for a left-turn phase in a traffic signal phasing sequence and the period of operation;
- the timing of left-turn phases;
- the timing of clearance intervals;
- the traffic signal indications that should be displayed for each of the left-turn phasing alternatives.

The objectives of this study are:

- the development of standard practices to be used in the determination of vehicle clearance intervals and the need for and timing of left-turn phases in the operation of traffic signals;
- the development of standardized configurations for traffic signal indications to be used to control left-turn movements.

The lack of application of the current standards for the foregoing became apparent in the survey of practices across Canada which was carried out in the first phase of the project.

In this second phase of the project, a series of questionnaires and meetings with practicing traffic engineers was used to supplement the research from the first phase of the project as a means of developing a recommended practice for the timing and phasing of traffic signals as well as for the signal indication displays that are associated with the various left-turn phasing alternatives. Recent research was used to develop a recommended practice for the timing of vehicle clearance intervals in traffic signals.

2.0 DEFINITIONS

Throughout this report, terminology is used which, in order to ensure consistency, conforms to the following definitions:

General

1. Permissive Left Turns

   The left-turn driver has the opportunity to turn, permissibly, when adequate gaps appear in opposing traffic. The driver must yield the right-of-way to opposing vehicular and pedestrian traffic.

2. Protected Left Turns

   The left-turn driver is directed to turn left in a protected manner through a signal display and left-turn traffic has the right-of-way over the opposing vehicular and pedestrian traffic.

Protected/Permissive Left-Turn Phasing

The left-turn driver is first directed to turn left in a protected manner through a signal display and then given the opportunity to turn, permissibly, when adequate gaps appear in opposing traffic, through the display of a circular green. This can be provided in the following forms:

Advanced Green - a protected left turn, during which all traffic on the principal approach (the approach favoured with a signal phase to accommodate a left-turn movement) only may enter the intersection is provided and is followed by permissive left turns during an interval in which all traffic on the principal approach and in the opposing direction is permitted to enter the intersection.

Leading Simultaneous Left Turn - a protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is followed by permissive left turns during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection.

Permissive/Protected Left Turn

The left-turn driver is first given the opportunity to turn, permissibly, when adequate gaps appear in opposing traffic and then directed to turn left in a protected manner through a signal display. This can be provided in the following forms:

Extended Green - Permissive left turns are allowed during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection followed by an interval with a protected left turn during which all traffic on the principal approach only may enter the intersection.

Lagging Simultaneous Left Turns - Permissive left turns may be made during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection followed by an interval during which protected simultaneous left turns may enter the intersection from opposing approaches.

Exclusive Protected Left Turns

Left turns, entering the intersection from one or opposing approaches simultaneously, are directed to proceed only through the display of a green arrow. This type of phasing can take the form of an exclusive protected left-turn phase either preceeding or following the through movement phase. In this report these are referred to as:

Leading Exclusive Protected Left Turn - A protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is followed by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

Lagging Exclusive Protected Left Turn - A protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is preceded by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

As well, this type of phasing can take the form of an:

Advanced Exclusive Protected Left Turn - A protected left turn, for traffic entering the intersection from one approach only, is provided while allowing concurrent through and right-turning traffic on the same approach and is followed by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

Extended Exclusive Protected Left Turn - A protected left turn, for traffic entering the intersection from one approach only, is provided while allowing concurrent through and right-turning traffic on the same approach and is preceded by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

Separate Protected Left Turn

All traffic, including the left turns, is directed to enter the intersection from one approach at a time while the traffic on all other approaches is stopped.

3.0 METHODOLOGY

The first stage of the project used, as a base, the responses to the questionnaires in Phase 1 of the project, the literature review and contact with other agencies. A form was developed and provided to the study group members who were asked to identify the traffic signal indications which should be used to convey the messages associated with the various left-turn phasing options and intersection configurations.

The study group members were also provided with options for:

(a) the basis for determining the need for a left-turn phase;

(b) the basis for timing left-turn phases;

(c) the basis for timing the clearance intervals for left-turn phases;

(d) the basis for timing the clearance intervals for normal through (and other - left/right turn) - movements.

The responses to a questionnaire gave rise to a number of issues. These issues were summarized and presented to the study group.

A meeting was held in Vancouver on September 30, 1985. While a number of the issues were discussed, time did not permit consideration of all of the issues.

Those members of the study group attending the meeting were requested to provide a written response to the issues which were not discussed. Some of those members of the study group who were unable to attend the meeting provided comments on all of the issues.

Following the September 30, 1985 meeting, members of the study group were provided with a matrix of signal heads portraying the results of those items on which some concencus was reached at the meeting. Comments were also provided to members of the study group which suggested that, in respect to some of the traffic signal indications illustrated in the matrix, further consideration should be given to:

(i) the signal indications used for protected/permissive leading simultaneous and permissive/protected lagging simultaneous left-turn phases when there is a signal head solely for the purpose of providing an indication to motorists in a left-turn lane supplemented by traffic signal heads for the other traffic movements which take place at the intersection;

(ii) the use of a flashing left-turn arrow indication for exclusive/protected leading left-turn phasing and exclusive/protected lagging left-turn phasing.

The matrix illustrated signal indication displays related to the various phasing alternatives and modifications were suggested to the indications portrayed in the matrix. A supplementary questionnaire, to be completed by the study group members, accompanied the comments and the matrix. The questionnaire requested an indication of the agreement or disagreement and any comments related to the following proposals:

1. For Protected/Permissive Leading or Permissive/Protected Lagging Simultaneous Phasing, a signal head governing the left-turn lane only will display a red indication concurrently with the (flashing) green arrow.

2. For Exclusive/Protected Leading or Lagging Phasing:

   (a) the green arrow will operate in a flashing mode;

   (b) the signal heads governing other than left-turn lanes may contain a full circular green, or the appropriate 'through' and 'right-turn' arrows.

In addition, study group members were provided with explanatory notes relating to:

- issus related to the basis for determining the need for a left-turn phase;
- issues related to the basis for timing left-turn phases;
- issues related to the timing of clearance intervals for normal through movements.

Based on the summaries of the responses, the conclusions reached by the Consultant on the minor issues were summarized and unresolved issues of principal concern were identified. The outstanding major issues and the conclusions reached on outstanding minor issues were set out in a memorandum of 1986 03 31 to the Study Group members. The outstanding major issues were:

(1) Should left-turn arrows be used in a flashing mode?

(2) If so, under what phasing alternative?

(3) When there is a separate left-turn lane and separate traffic signal heads, is there a need to display a red indication with the protected (leading or lagging) simultaneous phasing?

(4) As part of the clearance interval, is it better to use an amber ball following a green arrow (flashing or not) interval than an amber arrow in a permissive/protected (lagging) simultaneous phasing?

The Technical and Research (T&R) Committee of the Council on Uniform Traffic Control Devices for Canada met on April 7-8, 1986. At the end of the meeting, the foregoing issues were discussed without a resolution.

A further meeting, of one hour duration, was held prior to the Technical and Research Committee meeting in Toronto (in conjunction with the Roads and Transportation Association of Canada Annual Conference) on September 29, 1986. The first three issues listed above were discussed. Although it can be concluded that the issue of the use of a red indication in a traffic signal head governing a left-turn lane only was resolved, the use of a "flashing" green arrow indication was not.

It became apparent that, without further research to prove or disprove the statements in support of the "flashing" or the "non-flashing" mode of operation related to the green arrow indication, any attempt to resolve the issue through further deliberations of the study group would not likely be fruitfull.

Accordingly, the Consultant has assessed the valuable information provided by the study group participants and has developed proposals for the various elements which comprise the objectives of the project.

4.0 WARRANTS FOR LEFT-TURN PHASING

The study group was dominantly in favour of a warrant which addressed the number of lanes at the intersection, the ratio of the 'green' signal time to the cycle length (G/C), the left-turn traffic volumes and the opposing (through plus right-turn) traffic. The warrant should provide an interrelationship of these factors preferably in a table ("look-up") format.

While there is agreement that collision experience should form an element of a warrant for a left-turn phase in a traffic signal operation, there was no one expression of the collision experience that received significant support.

4.1 Geometric and Traffic Factors

The 1965 Highway Capacity Manual (HCM) defines a "service volume" as being the maximum number of vehicles that can pass over a given section of a lane or roadway in one direction on multilane highways (or in both directions on a two- or three-lane highway) during a specified time period while operating conditions are maintained corresponding to the selected or specified level of service. In the absence of a time modifier, service volume is an hourly volume.

The 1965 HCM considered each special turning lane as having the following "service volumes" per lane (10 feet in width):

Level	Vehicles per Hour of Green	Assumed Trucks (%)
A, B, C	800	5
D	1000	5
E (capacity)	1200	5

Essentially, the foregoing traffic volume value of 1200 vehicles per hour of green was considered to be the saturation flow.

The 1965 HCM in dealing with separate left-turn lanes (traffic signal controlled), suggested that the "service volume", in passenger cars, should be considered as the difference between 1200 vehicles (per hour of green) and the total opposing (through plus right-turn) traffic volume (Vo) (i.e., 1200-Vo) expressed in passenger cars per hour of green. In any circumstances the capacity would be not less than two vehicles per signal cycle.

Thus, it was necessary to apply a modifier to determine the capacity of a specific left-turn lane. The modifier is the ratio of the green signal time available to the cycle length (G/C). Thus, the capacity of a left-turn lane was calculated to be (1200 (G/C) - Vo).

This formula did not address the fact that opposing traffic may be accommodated in more than one lane.

In the Transportation Research Circular containing the interim materials on highway capacity (signalized intersections) the following formula appears:

$$V_L = (G/C)(1200) - Vo$$

Where:

V_L = Left-turn volume, in vph, that can clear through opposing traffic on the green interval.

G/C = Green time/Cycle time ratio for opposing flow (Vo). If no other design information is available, estimate by lane volume ratio.

Vo = Volume of Opposing through plus right-turn traffic, in vph.

Note that the green time in the G/C ratio is considered as the green interval plus the change interval.

In the 1985 HCM, it was indicated that, in respect to a left-turn movement, the maximum flow rate that may be assigned to the permitted portion of a (protected plus permitted) phase is the capacity of the permitted phase, computed as the maximum of:

Capacity (left turn) = $(1400 - Vo)(G/C)_{PLT}$
or
= 2 vehicles per signal cycle

Where:

Vo = opposing through plus right-turn flow rate in v.p.h. and

$(G/C)_{PLT}$ = effective green ratio for the permitted left-turn phase (both terms are in seconds).

This formula is inconsistent with the principles of the 1965 HCM and the Transportation Resarch Circular interim material on the capacity of signalized intersections. Another difference between the 1965 and 1985 HCM methods is the increase in the value of 1200 to a value of 1400. A value of 1400 is more appropriate based on a review of information on saturation flow rates in both the 1985 HCM and the Canadian Capacity Guide for Signalized Intersections.

Substituting 1400 for 1200 in the 1965 HCM's formula, yields the following equation for the determination of the capacity of a left-turn lane:

$$C_{LT} = 1400\ G/C - Vo$$

If it can be assumed that vehicles can also clear on the amber portion of the change interval, the formula becomes:

$$C_{LT} = 1400\ G/C - Vo + LT_A \qquad (1)$$

Where:

LT_A = the number of vehicles that can clear each cycle on the amber portion of the clearance interval.

The 1985 HCM provides only a general description of the rather laborious methodology which must be used in dealing with the capacity associated with left turns. (Granted, one can use the computer program to perform the calculations; however, one should clearly understand the methodology before relying on the computer program).

One of the principal shortcomings of the 1985 HCM method (there are others that have been identified as reported in papers submitted to the 66th (1987) Annual Meeting of the Transportation Research Board) is the failure to recognize the impact of the opposing traffic being in more than one lane in the foregoing equation.

A discussion with the author of the 1985 HCM revealed that the 1985 HCM formula is based on the opposing flow being in more than one lane (although this is not stated in the HCM) and is typically in two lanes.

The following has been extracted from the Canadian Capacity Guide for Signalized Intersections.

The empirical left-turn saturation flow equation (page 17 of the Canadian Guide) applies directly only to situations where the opposing traffic flow is in one lane; adjustments are needed if a different number of "opposing" lanes is available. Research conducted in Toronto has identified the following required gap sizes and probabilities as a function of the number of opposing lanes. Table 4-1 reflects the fact that although longer gaps are needed if the number of lanes to be crossed is greater (and vice versa), the probability of accepting the gap increases with the number of lanes.

TABLE 4-1
LEFT-TURN GAPS AND PROBABILITIES

No. of Lanes of Opposing Traffic	Required Gap	Probability of Accepting Gap
1	4 sec/pcu	0.520
2	5 sec/pcu	0.820
3	6 sec/pcu	0.950
4	7 sec/pcu	0.986

As a result, the equation for the converted opposing volume can be modified as follows:

$$V_o' = (f)\ V_o \qquad (2)$$

Where:

V_o' = converted opposing volume (vehicles per hour)

V_o = total opposing volume (vehicles per hour)

(f) = a factor to represent the approximate gap probability and acceptance

With an opposing flow in	1	2	3	4	lanes
(f) =	1.0	0.625	0.5	0.44	

Thus, by combining equation (1) with equation (2), the capacity of a separate left-turn lane, without a separate phase for left turns can be estimated by the equation:

$$C_{LT} = 1400\ G/C - V_o' + LT_A$$
$$= 1400\ G/C - (f)Vo + LT_A \qquad (3)$$

Where:

C_{LT} = the capacity of the left-turn lane during a "permissive" green phase

(f) = a factor to represent the approximate gap probability and acceptance

With an opposing flow in	1	2	3	4	lanes
(f) =	1.0	0.625	0.5	0.44	

Vo = total opposing volume (includes opposing through lanes, shared lanes and right turns where channelization does not exist)

C = cycle time (seconds)

G = effective green interval for the opposing traffic flow (seconds)

LT_A = the number of vehicles turning left on amber on the approach under consideration.

Note that LT_A is a function of the opposing flow (if the opposing flow is at capacity the opportunity to turn left may be minimal) but should also reflect the behaviour of motorists in the community to which the analysis is being applied.

When a value of 1400 is applied, it can safely be assumed that some vehicles will clear on amber (LT_A). In large cities, the value (LT_A) of two vehicles per cycle has typically been used. In smaller municipalities, a value (LT_A) of one vehicle per cycle may be more appropriate.

A preliminary G/C ratio should be determined based on a signal phasing which does not include a left-turn phase for the approach under consideration.

Thus, equation (3) can be used to determine if and when a left-turn phase is warranted. If the left-turn capacity as estimated from equation (3) exceeds the left-turn demand, as measured or as may have been forecast for some future year/time, a separate left-turn phase is not warranted.

The analysis period is one hour. If conditions during a shorter period require evaluation, the traffic volumes for the shorter period should be expanded (factored) to represent a one hour volume. Normally, the traffic volume conditions should prevail for a one hour period before a left-turn phase is introduced into the operation of the traffic signals. In unusual circumstances, such a surge in traffic volumes for a period shorter than one hour (e.g., when a major industrial plant near an intersection experiences a shift change) the left-turn phase could operate during the period it is warranted. The technology used in the traffic signal controller must have the capability to be programmed to initiate and terminate the left-turn phase at the appropriate time.

A sample ("look-up" type) table is provided in Annex 1 which illustrates the relationship between an opposing traffic volume in two lanes and the G/C ratio. A G/C ratio ranging between 0.2 and 0.8 in increments of 0.02 (and the associated 'green' time) is provided above the relevant column. For any opposing traffic volume (in the case of the table in Annex 1 - opposing volume in two lanes) volume values in increments of 25 vph are provided in the rows for values ranging between 150 and 1300 vehicles per hour. Using the appropriate "opposing traffic" volume values and the appropriate G/C ratio, the capacity of a left-turn lane can be estimated from the table of values. The table in Annex 1 is based on the ability of the intersection to clear two vehicles per cycle in the change interval. Thus, based on a 90 second cycle (40 cycles per hour), 80 vehicles per hour would be accommodated during the clearance portion of the change interval.

4.2 Collision Factors

It is not possible, based on the study group's response to the options proposed for this aspect of the study related to the need for a left-turn phase, to be definitive in prescribing a "collision warrant".

Collision experience should be included in the evaluation of the need for a left-turn phase. A local rate should be determined for left-turn collisions and the experience at a particular intersection should be compared to that rate. If it exceeds the rate, there is support for a left-turn phase.

Where a local rate is not easily derived, the following guidelines should be used to determine the need for a left-turn phase:

(a) for one approach, 4 left-turn collisions in one year or 6 in two years;

(b) for both approaches, 6 left-turn collisions in one year or 10 in two years.

5.0 TIMING LEFT-TURN PHASES

A slight majority of the study group favoured the use of a headway value related to a level of service for the purposes of determing the timing of a left-turn phase. A relationship of this nature would be akin to the traffic signal timing methods often referred to as the Northwestern method, the MTC (Ministry of Transportation and Communications) method and the Ewens method.

There was also a slight majority of the study group that favoured a reference to some Volume/Capacity (V/C) relationship as determined using the method described in the Canadian Capacity Guide for Signalized Intersections. Some respondents favoured both the use of headways and a V/C relationship.

There are a number of traffic signal timing methods currently in use (i.e., SOAP (signal operation analysis package, the 1985 HCM) in addition to those referred to above. Officials in most provinces and large municipalities (i.e., those represented on the Study Group) will be using a method which is felt to meet their needs and it may or may not be one of the foregoing.

For other jurisdictions (smaller municipalities), a simplified method is more appropriate. The timing of left-turn phases should be based on a headway value related to the intersection locale.

Level of Service and its relationship to capacity is characterized in different ways depending upon the methodology. The 1985 Highway Capacity Manual uses measures of delay while the Ministry of Transportation and Communications methodology uses the probability of clearing an intersection during the green interval for those vehicles arriving during a complete cycle. The 1965 Highway Capacity Manual used a "load factor" to quantify the level of service. The Canadian Capacity Guide for Signalized Intersections makes no reference to level of service. For the purposes of this report, a qualitative description of the level of service is adequate. The following is based on the descriptions of Level of Service in the 1965 HCM and the Ministry of Transportation and Communications methodology. The descriptions are included here solely to provide an appreciation for the term "Level of Service".

LEVEL OF SERVICE "A" - No signal phase is fully utilized by traffic and no vehicle waits longer than one red indication. The approach appears open, turning movements easily made and drivers have freedom of operation.

LEVEL OF SERVICE "B" - An occasional signal phase is fully utilized and many phases approach full use. Many drivers begin to feel somewhat restricted within platoons of vehicles approaching the intersection.

LEVEL OF SERVICE "C" - The operation is stable with more frequent fully utilized signal phases. Drivers feel more restricted and occasionally may have to wait through more than one red signal indication and queues may develop behind turning vehicles.

LEVEL OF SERVICE "D" - The motorist experiences increasing restriction and instability of flow. *There are enough cycles with lower demand to permit* occasional clearance of developing queues and prevent excessive back-ups.

LEVEL OF SERVICE "E" - This represents capacity. There are long queues of vehicles waiting upstream of the intersection and delays to vehicles may be more than one signal cycle.

In order to provide some guidelines for officials in smaller municipalities to determine the appropriate timing for left-turn phases, Table 5-1 is provided.

Since it is not normal practice to provide a "level of service" which is better than Level of Service "C" for a left-turn phase, Table 5-1 provides suggested values for Levels of Service C, D and E.

TABLE 5-1

LEFT-TURN PHASE TIMING

	Number of Seconds		
	Small Urban Area	**Medium Urban Area**	**Large Urban Area**
Level of Service "C"			
First two vehicles	13	12	10
Each additional vehicle	3.0	2.5	2.25
Level of Service "D"			
First two vehicles	11	10	8
Each additional vehicle	2.5	2.25	2.25
Level of Service "E"			
First two vehicles	9	8	7
Each additional vehicle	2.5	2.25	2.0

In large municipalities, the minimum length of a left-turn phase should be not less than 5 seconds. In small municipalities, the minimum length of a left-turn phase should be not less than 7 seconds.

A higher minimum value should be established, if necessary, based on:

- field studies;
- unusually wide intersections;
- the case where left-turn detectors are set back from the stop line;
- unusually high number of heavy vehicles;
- the grade on the left-turn approach to the intersection;
- a rural environment.

6.0 TIMING CHANGE INTERVALS

The timing of the change interval (amber plus "all red", if used) in a traffic signal has always been and remains controversial as witnessed by the number of papers which have been written on the subject (see State-of-the-Art Report on Phase 1 of this project).

Subsequent to the research undertaken in the preparation of the 'State-of-the-Art' Report, Committee 4A-16 of the Institute of Transportation Engineers (ITE) proposed a recommended practice; although, at the time of writing of this report, the proposal has not been adopted as a recommended practice by ITE.

The responses from the study group dominantly favoured the proposed recommended practice as is described in an article entitled "Determining Vehicle Change Intervals" (by ITE Technical Committee 4A-16) in the Institute of Transportation Engineers Journal, May 1985.

In addition, a significant majority of the responses to the questionnaire indicated that the amber portion of the change interval should be a minimum of three seconds; although, some respondents favoured four seconds as a minimum.

A majority of the respondents to the questionnaire indicated that the "all red" portion of the change interval, when used, should have a minimum length of one second.

The formulae as contained in the foregoing I.T.E. article have been converted to use the terms "amber" and "kilometres per hour" in the following:

(1) Amber Portion of Change Interval

The formula for determining the length of the amber interval is:

$$y = t + \frac{v}{2a + 2Gg}$$

where:

- y = length of the amber interval, to the nearest 0.1 second;
- t = driver perception/reaction time, recommended as 1.0 second;
- v = velocity of approaching vehicle, in kilometres per hour;
- a = deceleration rate, (recommended as 11.0 km/h/second);
- G = acceleration due to gravity, (35.3 km/h/second);
- g = grade of approach, in percent divided by 100 (downhill is negative grade).

(2) Red Portion of the Change Interval

Depending on the policy of the local agency, the red clearance interval timing can be determined by one of the following:

$$r = 3.6 \frac{W + L}{V} \qquad (1)$$

$$r = 3.6 \frac{P}{V} \qquad (2)$$

$$r = 3.6 \frac{P + L}{V} \qquad (3)$$

where:

- r = length of the red clearance interval, to the nearest 0.1 second.
- W = width of the intersection, in metres, measured from the near side stop line to the far side edge of the conflicting traffic lane along the actual vehicle path.
- P = width of intersection, in metres, measured from the near side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path.
- L = length of vehicle, recommended as 6 m.
- V = speed of the vehicle through the intersection, in kilometres per hour.
- 3.6 = conversion factor (one metre per second = 3.6 kilometres per hour).

In order to provide a simple means by which the foregoing formulae can be applied, the two formulae have been converted to tables which enable the user to select the appropriate value.

Table 6-1 provides the values which should be applied for the amber clearance portion of the change interval, depending on the speed and the grade on the approach to the intersection. These values should also be applied to the amber or amber arrow portion of the change interval following the green/green arrow interval of a left-turn phase. For application in the context of the change interval related to a left-turn phase, an approach speed should be used which is lower than the approach speed related to the through traffic movement. No values below 3.0 seconds are provided as this value is considered to be the minimum value that should be used under any circumstances.

As suggested in the aforementioned ITE article, "While the determination of the slope of roadway approaches is rather straightforward, the remaining variable, V (vehicle speed), can be more difficult to determine. The speed is generally taken to be that represented by a locally chosen percentile of approach speeds, usually the 85th percentile, although it may be possible to use the posted speed limit as the approach speed. Such a policy may not be unreasonable given that drivers approaching at higher speeds are violating the law. Care should be taken to assure that the speed limit is reasonable. Determining the approach speed to use for timing the yellow interval for protected turn phases is more complicated than for through phases due to the changing approach speed of vehicles preparing to make a turn. Turning vehicles may be either approaching at through vehicle

TABLE 6-1

AMBER PORTION OF CHANGE INTERVAL (IN SECONDS)

Grade (%)		Approach Speed in km/h															
		25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
UPHILL	10	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.1	3.3	3.4	3.6	3.8	4.0	4.1	4.3	4.5
	8	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.2	3.4	3.6	3.7	3.9	4.1	4.3	4.5	4.6
	6	3.0	3.0	3.0	3.0	3.0	3.0	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.8	
	5	3.0	3.0	3.0	3.0	3.0	3.0	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	
	4	3.0	3.0	3.0	3.0	3.0	3.0	3.2	3.4	3.6	3.8	4.1	4.3	4.5	4.7	4.9	5.1
	3	3.0	3.0	3.0	3.0	3.0	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.6	4.8	5.0	5.2
	2	3.0	3.0	3.0	3.0	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.7	4.9	5.1	5.3
	1	3.0	3.0	3.0	3.0	3.0	3.2	3.5	3.7	3.9	4.1	4.3	4.6	4.8	5.0	5.2	5.4
	0	3.0	3.0	3.0	3.0	3.1	3.3	3.5	3.8	4.0	4.2	4.4	4.7	4.9	5.1	5.4	5.6
DOWNHILL	-1	3.0	3.0	3.0	3.0	3.1	3.4	3.6	3.8	4.1	4.3	4.5	4.8	5.0	5.3	5.5	5.7
	-2	3.0	3.0	3.0	3.0	3.2	3.5	3.7	3.9	4.2	4.4	4.7	4.9	5.2	5.4	5.6	5.9
	-3	3.0	3.0	3.0	3.0	3.3	3.5	3.8	4.0	4.3	4.6	4.8	5.1	5.3	5.6	5.8	6.1
	-4	3.0	3.0	3.0	3.1	3.4	3.6	3.9	4.2	4.4	4.7	4.9	5.2	5.5	5.7	6.0	6.3
	-5	3.0	3.0	3.0	3.2	3.5	3.7	4.0	4.3	4.6	4.8	5.1	5.4	5.6	5.9	6.2	6.5
	-6	3.0	3.0	3.0	3.1	3.6	3.8	4.1	4.4	4.7	5.0	5.3	5.5	5.8	6.1	6.4	6.7
	-8	3.0	3.0	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.2	6.5	6.8	7.2
	-10	3.0	3.0	3.4	3.7	4.0	4.4	4.7	5.1	5.4	5.7	6.1	6.4	6.7	7.1	7.4	7.7

amber clearance interval: $y = t + \frac{V}{2a + 2Gg}$

Where:
- t = 1.0 second perception time
- V = approach speed in km/h
- a = (11.0 km/h)/sec (deceleration rate)
- G = (35.3 km/h)/sec (acceleration rate due to gravity)
- g = grade of approach in percent divided by 100 (downhill is negative)

Source: adapted from: "Determining Vehicle Change Intervals", ITE Journal, May 1985.

Values have been rounded from two significant digits to one significant digit by rounding to the next highest 0.1 from any value of 0.03 to 0.09

speed and slowing down to a safe turning speed, or accelerating from a stop condition in a queue. Appropriate selection of approach speed can allow one to produce a good approximation of the timing needed."

Following Table 6-1 are the guidelines suggested for determining the length of the "red clearance interval".

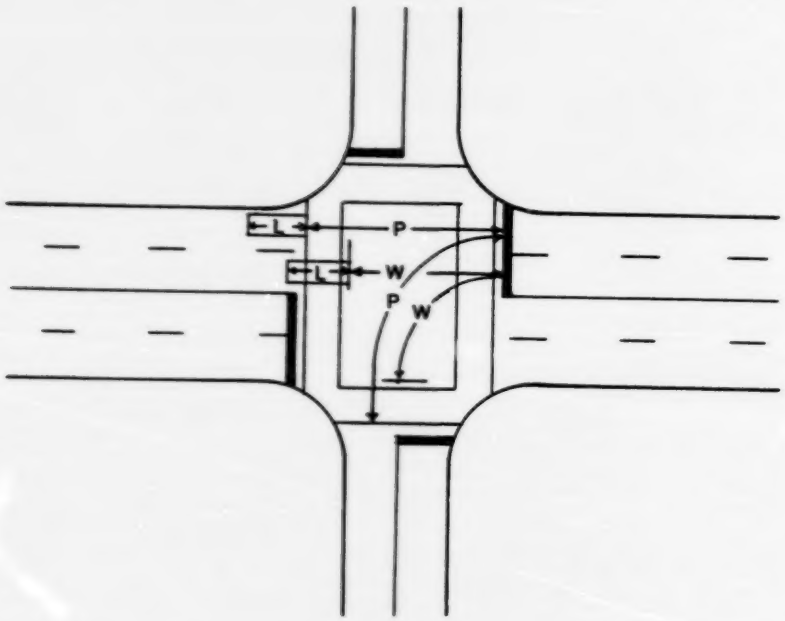
As indicated in the aforementioned ITE article, "To a substantial extent, the need for red clearance intervals is predicated on the local jurisdiction's policy regarding the necessity of an absolute provision of time for vehicles that entered on yellow to clear the area of conflict before the right-of-way is reassigned. As vehicles may legally enter the intersection during the display of the yellow indication, the yellow interval is not a clearance interval . . . . . " and "If it is the policy of the local agency to provide clearance time, the traditional practice has been to either add the time to the yellow interval, or to use what has previously been called the "all red interval" " (referred to as the red clearance interval). It is proposed by ITE Committee 4A-16 that the policy of ITE be that if clearance time is to be provided, it should be in the form of a red clearance interval.

The red portion of the change interval (or red clearance interval) is dependent on the selection of the appropriate "case" and its associated "clearing distance". In this regard, there are three "cases" as described in the following. In the equations, the distances P, L and W are as described and illustrated below.

W = Width of the intersection, in metres, measured from the near side stop line to the far side edge of the conflicting traffic lane along the actual vehicle path (a curved line in the case of a left turn).

P = Width of the intersection, in metres, measured from the near side stop line to the far side of the farthest conflicting pedestrian crosswalk along the actual vehicle path (a curved line in the case of a left turn).

L = 6.0 m average vehicle length (ITE uses a 6.1 m length).



The three "cases" are:

Case 1: Clearing distance is based on no pedestrian traffic - use (W+L)

"All red" portion of the change interval = (r) = $3.6 \frac{(W+L)}{V}$

Case 2: Clearing distance is based on some probability of pedestrian traffic - use P.

"All red" portion of the change interval = (r) = $3.6 \frac{P}{V}$

Use the value from Case 1 and Case 2 which yields the largest value.

Case 3: Clearing distance is based on significant pedestrian traffic or where pedestrian signals have been provided - use (P+L).

"All red" portion of the change interval = (r) = $3.6 \frac{P+L}{V}$

If there is any doubt as to which "case" to use, base the clearing distance on "Case 3".

Table 6-2 provides the values which should be applied for the all-red portion of the change interval depending on the "clearing distance" and the speed. Thus, for a given intersection approach, the "clearing distance" to be used for determining the clearance interval must first be established (i.e., Case 1, Case 2 or Case 3). Once the clearing distance is established, enter the table with the clearing distance and the approach speed and the value for the all-red portion of the change interval is given. No values below 1.0 second are provided as this is considered to be the minimum value that should be used under any circumstances.

TABLE 6-2

ALL-RED PORTION OF CHANGE INTERVAL (IN SECONDS)

Clearing Distance (m)	Speed (km/h)										
	25	30	35	40	45	50	60	70	80	90	100
12.0	1.7	1.4	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0	1.0
13.5	1.9	1.6	1.4	1.2	1.1	1.0	1.0	1.0	1.0	1.0	1.0
15.0	2.2	1.8	1.5	1.4	1.2	1.1	1.0	1.0	1.0	1.0	1.0
16.5	2.4	2.0	1.7	1.5	1.3	1.2	1.0	1.0	1.0	1.0	1.0
18.0	2.6	2.2	1.9	1.6	1.4	1.3	1.1	1.0	1.0	1.0	1.0
19.5	2.8	2.3	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0	1.0
21.0	3.0	2.5	2.2	1.9	1.7	1.5	1.3	1.1	1.0	1.0	1.0
22.5	3.2	2.7	2.3	2.0	1.8	1.6	1.4	1.2	1.0	1.0	1.0
24.0	3.5	2.9	2.5	2.2	1.9	1.7	1.4	1.2	1.1	1.0	1.0
25.5	3.7	3.1	2.6	2.3	2.0	1.8	1.5	1.3	1.1	1.0	1.0
27.0	3.9	3.2	2.8	2.4	2.2	1.9	1.6	1.4	1.2	1.1	1.0
28.5	4.1	3.4	2.9	2.6	2.3	2.1	1.7	1.5	1.3	1.1	1.0
30.0	4.3	3.6	3.1	2.7	2.4	2.2	1.8	1.5	1.4	1.2	1.1
31.5	4.5	3.8	3.2	2.8	2.5	2.3	1.9	1.6	1.4	1.3	1.1
33.0	4.8	4.0	3.4	3.0	2.6	2.4	2.0	1.7	1.5	1.3	1.2
34.5	5.0	4.1	3.5	3.1	2.8	2.5	2.1	1.8	1.6	1.4	1.2
36.0	5.2	4.3	3.7	3.2	2.9	2.6	2.2	1.9	1.6	1.4	1.3
37.5	5.4	4.5	3.9	3.4	3.0	2.7	2.3	1.9	1.7	1.5	1.4
39.0	5.6	4.7	4.0	3.5	3.1	2.8	2.3	2.0	1.8	1.6	1.4
40.5	5.8	4.9	4.2	3.6	3.2	2.9	2.4	2.1	1.8	1.6	1.5
42.0	6.0	5.0	4.3	3.8	3.4	3.0	2.5	2.2	1.9	1.7	1.5
43.5	6.3	5.2	4.5	3.9	3.5	3.1	2.6	2.2	2.0	1.7	1.6
45.0	6.5	5.4	4.6	4.1	3.6	3.2	2.7	2.3	2.0	1.8	1.6

Source: adapted from: "Determining Vehicle Change Intervals", ITE Journal, May 1985.

7.0 GEOMETRY, SIGNAL PHASING AND SIGNAL INDICATIONS INTERRELATIONSHIP

The display of an array of traffic signal indications is related to the traffic signal phasing as well as to the intersection geometry.

7.1 Intersection Geometry

Intersection geometry will influence, to some degree, the phasing which is applied; although, the principal determinant will be the traffic volumes.

The relationship of the traffic signal head location to the various geometric configurations is not addressed specifically in this project as it is being considered in a project entitled "Uniform Traffic Signal Display" (Project Number 158) under the auspices of the Council on Uniform Traffic Control Devices for Canada, Technical and Research Committee.

Suffice it to say that, for some geometric configurations, it may be appropriate to install traffic signal heads with the appropriate indications where a specific group of motorists (in a left-turn lane, for example) is provided with its own specifically aimed traffic signal head. Often this is in the form of a "programmable" traffic signal indication. Other groups of motorists (those in a through traffic lane or a lane from which a right turn is made) must, in such circumstances, be provided with a signal head which contains indications governing their movements.

In other circumstances, it is not possible or may not be appropriate to dedicate traffic signal heads to a specific lane group. In these circumstances, it is necessary to install traffic signal heads which must contain indications which are "shared" by all lane groups regardless of the intersection geometry.

The traffic signal indications as referred to in Section 7.3, provide proposals for traffic signal heads which govern "left-turn lanes" and "other than left-turn lanes". In some of the phasing alternatives, traffic signal indications are proposed for traffic signal heads which are "shared" by motorists in all lanes. When "shared" traffic signal indications are illustrated, no attempt has been made to define the geometric circumstances under which these "shared" signal heads should be used or where traffic signal heads should be positioned in relation to the approach lanes under the various intersection configurations in cases where such signal heads would govern specific lanes.(1) There are, however, cases where signal indications for some of the phasing alternatives should only be used where left-turn lanes are available. The exhibits for these phasing alternatives do not include proposals for "shared" signal heads.

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(1) The relationship of the traffic signal head location to various geometric configurations is being considered in a project entitled "Uniform Traffic Signal Display" (Project Number 158) under the auspices of the Council on Uniform Traffic Control Devices for Canada, Technical and Research Committee.

7.2 Traffic Signal Phasing

There are nine basic left-turn phasing alternatives as follows:

(a) Alternatives in which there may be "shared" traffic signal indications:

PROTECTED/PERMISSIVE
- Advanced Green

PERMISSIVE/PROTECTED
- Extended Green

PROTECTED/PERMISSIVE
- Leading Simultaneous Left Turn

PERMISSIVE/PROTECTED
- Lagging Simultaneous Left Turn

(b) Alternatives in which there should be no "shared" traffic signal indications:

EXCLUSIVE PROTECTED
- Leading Exclusive Protected Left Turn
- Lagging Exclusive Protected Left Turn
- Advanced Exclusive Protected Left Turn
- Extended Exclusive Protected Left Turn

(c) An infrequently used phasing alternative in which there may be "shared" traffic signal indications:

SEPARATE PROTECTED LEFT TURN

The protected/permissive left-turn phasing (in both of its forms) has been the most common type of phasing for many years. The permissive protected left-turn phasing (in both of its forms) has also been in use; although, to a more limited degree for essentially the same number of years.

The various exclusive/protected forms of left-turn phasing have emerged over the past few years primarily in an attempt to meet the safety needs of particular combinations of intersection configuration and intersection traffic volumes.

Current traffic signal controller technology allows left-turn phases of various lengths to be provided or to be "skipped" if there is no demand for a particular left-turn phase. These factors have, possibly more than any other factor, led to the need to adopt uniformity in the indications given to motorists.

A recent report prepared for the National Cooperative Highway Research Program of the Transportation Research Board of the United States National Research Council entitled "Traffic Signal Display Complexity" contains the following:

> "Motorists understand the meaning of the various individual signal indications including green, yellow, and red circular and arrow displays when used for prohibited, permitted, and protected movements when these signal indications have a clear, unique, and unambiguous meaning. Green arrows imply protected movements and must be used in the absence of vehicle and pedestrian conflicts. The control for each movement must be clearly indicated by the signal display and not implied from an indication for a different movement (e.g., a straight through green arrow should not be used to imply that left turns are prohibited; a left-turn red arrow should be used in addition if it is desired to prohibit left turns) (1).
>
> With the increased use of signal phasing and separate movement control it is inevitable that conflicting display indications will arise. The effect of these conflicting indications can be minimized by insuring that the intended display is clearly associated with a particular movement."

The report indicates that there are two specific points derived from the research undertaken:

1. Each Signal display should have a clear, unique, unambiguous meaning. Furthermore, the signal indication should not be used to imply a different control for another movement.
2. The use of supplemental signs is to be minimized. Temporary signs might be used for a few months at new intersections and permanent turn signal designation signs are acceptable. While time and/or use restriction signs may be necessary, their use should be minimized wherever possible.

It is important therefore that the indications which are given to motorists are consistent. This is particularly important when, for example, a protected/permissive leading simultaneous left-turn phasing becomes a protected/permissive advanced phasing as a consequence of one of the left turns not being "called".

Similarly, an exclusive/protected leading simultaneous phasing can become an exclusive/protected advanced phasing if there is no "call" for one of the opposing left turns.

The ability of current traffic signal controller technology to allow, selectively, the termination of one of the left-turn phases, in the case of a "simultaneous" phasing, dictates the need to ensure that the motorist is given a clear and consistent indication when the circumstances confronting the motorist and his expected behaviour are the same.

---

(1) Since Canadian practice does not recognize the left-turn red arrow, this example, which is quoted from the report, is not relevant.

When, for any given approach, the indications comprising a traffic signal head are different for different lane groups, there should be two signal heads, each with a set of all indications.

7.3 Signal Indications

Exhibits 1 to 9 in Annex 2 illustrate the signal indications which are proposed to be used for each of the nine phasing alternatives.

The proposed signal indications for the various phasing alternatives have been developed from the responses to the questionnaires and discussions at study group meetings and with study group members. The proposals do not represent the agreement of all persons involved in the study group but rather the author's assessment of the preferred indications.

Although the study group which was involved in this project agreed that the signal indications should be based on the various left-turn phasing alternatives and not on the various geometric alternatives, the following comments are included for the purposes of assisting those who are involved in the project entitled "Uniform Traffic Signal Display" (Project Number 158) under the auspicies of the Council on Uniform Traffic Control Devices for Canada, Technical and Research Committee.

The indications for all of the protected/permissive and permissive/protected phasing alternatives can be applied to both undivided and divided intersection configurations.

According to the report "A Study of Clearance Intervals, Flashing Operation and Left-Turn Phasing at Traffic Signals", (See Phase 1 Report) it is common practice to provide median mounted left-turn heads for protected/permissive and permissive/protected phasing alternatives; however, the conclusion, as stated in the report, is that median mounted left-turn signals should be reserved for full-time protected phasing and that protected/permissive signal indications be displayed by either span wires or mast arms.

In undivided intersection configurations only "shared" signal heads should be used unless there are particular circumstances which dictate the need for signal heads which govern a particular lane group.

When, in the phasing alternatives for which signal heads are installed specifically for a left-turn lane, it is essential, as well, that, for both the left-turn lane group and other than left-turn lane groups, the signal heads are positioned relative to the lanes they govern and/or that programmable traffic signal indications are used effectively. The use of a "left-turn signal" designation sign is also recommended as a preferred practice; however, such a sign is not mandatory in all circumstances. This sign should have the sole purpose of identifying the traffic signal head which governs the movement of drivers intending to make a left turn. No sign should be installed which attempts to clarify or qualify the meaning of the traffic signal indications.

The signal indications for all of the exclusive/protected phasing alternatives are predicated on the use of signal heads which govern a left-turn lane and other signal heads for the purposes of governing the other lane groups.

As indicated earlier, the location of signal heads is being addressed by a study group under the auspices of the Technical and Research Committee of the Council on Uniform Traffic Control Devices. It is not the purpose of this report to propose the use of signal heads in relation to the combination of geometric configurations and phasing alternatives. Rather it is intended that the various possible displays of signal indications be uniform for each of the phasing alternatives. For this reason, the displays of indications provide for the possibility of using traffic signal heads dedicated to particular lane groups or using "shared" traffic signal heads.

It will be noted that, also for all of the exclusive/protected phasing alternatives, the recommended practice proposes the use of a full circular green indication for signal heads governing other than the left-turn lanes. An option is provided which would allow the use of a four section signal head with "straight through" (upward pointing) and "right-turn" arrow indications.

There are two concerns with the use of the arrow indications under these circumstances. One of these is the conspicuity of the arrow signal indication and the other relates to the conflict between right-turning vehicles and pedestrians, since motorists interpret an "arrow" indication as conveying the message that a "protected" turn may be made in the direction indicated by the arrow.

This may not be a concern if pedestrians are not allowed to use the crosswalk through which the right turn would be made while the right-turn arrow indication is illuminated or where the right-turn movement is "channelized".

The matter of flashing the left-turn arrow indications was the subject of extensive deliberation by the study group; however, no clear concencus was reached as to whether or not a "flashing" left-turn arrow indication should be used and, if so, the phasing alternatives in which the flashing mode would be recommended.

Although the Canadian Capacity Guide for Signalized Intersections indicates that "Flashing left turn signal indications generally induce a more expedient driver response than solid displays as evidenced by higher saturation flow values, especially for short advanced phases" further research is necessary in order to substantiate the benefits of the use of a "flashing" left-turn arrow.

There are factors which mitigate against the use of a "flashing" arrow. One is the problem of monitoring the presence of conflicting indications using a conflict monitor with certain types of solid state traffic signal controllers. Another factor is that the United States practice does not recognize the use of a flashing green arrow (or, for that matter, a flashing circular green). While it is likely that the technology problem can be overcome and it is acknowledged that there are other inconsistencies between Canadian and United States practices and standards, there does not seem to be a compelling reason to adopt the flashing operation of a green arrow signal indication at this time.

8.0 CONCLUSIONS

Proposed guidelines have been developed with the valuable assistance of the members of the study group and are described in the foregoing. These guidelines relate to:

- the warrants for left-turn traffic signal phasing;
- the timing of left-turn phases;
- the timing of change intervals;
- the traffic signal indications to be used for the control of left-turn movements at traffic signal controlled intersections.

The proposed guidelines should be considered by the Technical and Research Committee of the Council on Uniform Traffic Control Devices for Canada for inclusion in the Manual of Uniform Traffic Control Devices for Canada.

The suggested text which would give effect to the proposals contained in this report is provided in a separate document for consideration by the Technical and Research Committee of the Council on Uniform Traffic Control Devices for Canada.

ANNEX 1

WARRANTS FOR LEFT-TURN PHASING
SAMPLE LOOK-UP TABLE

OPP. Saturation Flow 1500

L.T. Saturation Flow 1400

Left Turns on Amber per Cycle 2

2 OPPOSING THRU LANES

80 SECOND CYCLE LENGTH

Opposing Traffic Volume	Green Time / Cycle Length Ratio																													
	0.20	0.22	0.24	0.26	0.28	0.30	0.32	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54	0.56	0.58	0.60	0.62	0.64	0.66	0.68	0.70	0.72	0.74	0.76	0.78	0.80
	Green Time - seconds																													
	16	17.6	19.2	20.8	22.4	24	25.6	27.2	28.8	30.4	32	33.6	35.2	36.8	38.4	40	41.6	43.2	44.8	46.4	48	49.6	51.2	52.8	54.4	56	57.6	59.2	60.8	62.4	64
225	229	257	285	313	341	369	397	425	453	481	509	537	565	593	621	649	677	705	733	761	789	817	845	873	901	929	957	985	1013	1041	1069
250	214	242	270	298	326	354	382	410	438	466	494	522	550	578	606	634	662	690	718	746	774	802	830	858	886	914	942	970	998	1026	1054
275	198	226	254	282	310	338	366	394	422	450	478	506	534	562	590	618	646	674	702	730	758	786	814	842	870	898	926	954	982	1010	1038
300	183	211	239	267	295	323	351	379	407	435	463	491	519	547	575	603	631	659	687	715	743	771	799	827	855	883	911	939	967	995	1023
325	167	195	223	251	279	307	335	363	391	419	447	475	503	531	559	587	615	643	671	699	727	755	783	811	839	867	895	923	951	979	1007
350	151	179	207	235	263	291	319	347	375	403	431	459	487	515	543	571	599	627	655	683	711	739	767	795	823	851	879	907	935	963	991
375	136	164	192	220	248	276	304	332	360	388	416	444	472	500	528	556	584	612	640	668	696	724	752	780	808	836	864	892	920	948	976
400	120	148	176	204	232	260	288	316	344	372	400	428	456	484	512	540	568	596	624	652	680	708	736	764	792	820	848	876	904	932	960
425	104	132	160	188	216	244	272	300	328	356	384	412	440	468	496	524	552	580	608	636	664	692	720	748	776	804	832	860	888	916	944
450	90	117	145	173	201	229	257	285	313	341	369	397	425	453	481	509	537	565	593	621	649	677	705	733	761	789	817	845	873	901	929
475	90	101	129	157	185	213	241	269	297	325	353	381	409	437	465	493	521	549	577	605	633	661	689	717	745	773	801	829	857	885	913
500	90	90	113	142	170	198	226	254	282	310	338	366	394	422	450	478	506	534	562	590	618	646	674	702	730	758	786	814	842	870	898
525	90	90	98	126	154	182	210	238	266	294	322	350	378	406	434	462	490	518	546	574	602	630	658	686	714	742	770	798	826	854	882
550	90	90	90	110	138	166	194	222	250	278	306	334	362	390	418	446	474	502	530	558	586	614	642	670	698	726	754	782	810	838	866
575	90	90	90	95	123	151	179	207	235	263	291	319	347	375	403	431	459	487	515	543	571	599	627	655	683	711	739	767	795	823	851
600	90	90	90	90	107	135	163	191	219	247	275	303	331	359	387	415	443	471	499	527	555	583	611	639	667	695	723	751	779	807	835
625	NA	90	90	90	91	119	147	175	203	231	259	287	315	343	371	399	427	455	483	511	539	567	595	623	651	679	707	735	763	791	819
650	NA	90	90	90	90	104	132	160	188	216	244	272	300	328	356	384	412	440	468	496	524	552	580	608	636	664	692	720	748	776	804
675	NA	NA	90	90	90	90	116	144	172	200	228	256	284	312	340	368	396	424	452	480	508	536	564	592	620	648	676	704	732	760	788
700	NA	NA	90	90	90	90	101	129	157	185	213	241	269	297	325	353	381	409	437	465	493	521	549	577	605	633	661	689	717	745	773
725	NA	NA	NA	90	90	90	90	113	141	169	197	225	253	281	309	337	365	393	421	449	477	505	533	561	589	617	645	673	701	729	757
750	NA	NA	NA	90	90	90	90	97	125	153	181	209	237	265	293	321	349	377	405	433	461	489	517	545	573	601	629	657	685	713	741
775	NA	NA	NA	90	90	90	90	90	110	138	166	194	222	250	278	306	334	362	390	418	446	474	502	530	558	586	614	642	670	698	726
800	NA	NA	NA	NA	90	90	90	90	94	122	150	178	206	234	262	290	318	346	374	402	430	458	486	514	542	570	598	626	654	682	710
825	NA	NA	NA	NA	90	90	90	90	90	106	134	162	190	218	246	274	302	330	358	386	414	442	470	498	526	554	582	610	638	666	694
850	NA	NA	NA	NA	NA	90	90	90	90	91	119	147	175	203	231	259	287	315	343	371	399	427	455	483	511	539	567	595	623	651	679
875	NA	NA	NA	NA	NA	90	90	90	90	103	131	159	187	215	243	271	299	327	355	383	411	439	467	495	523	551	579	607	635	663	
900	NA	NA	NA	NA	NA	NA	90	90	90	90	90	116	144	172	200	228	256	284	312	340	368	396	424	452	480	508	536	564	592	620	648
925	NA	NA	NA	NA	NA	NA	90	90	90	90	90	100	128	156	184	212	240	268	296	324	352	380	408	436	464	492	520	548	576	604	632
950	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	112	140	168	196	224	252	280	308	336	364	392	420	448	476	504	532	560	588	616
975	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	97	125	153	181	209	237	265	293	321	349	377	405	433	461	489	517	545	573	601
1000	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	109	137	165	193	221	249	277	305	333	361	389	417	445	473	501	529	557	585
1025	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	93	121	149	177	205	233	261	289	317	345	373	401	429	457	485	513	541	569
1050	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	106	134	162	190	218	246	274	302	330	358	386	414	442	470	498	526	554
1075	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	90	118	146	174	202	230	258	286	314	342	370	398	426	454	482	510	538
1100	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	103	131	159	187	215	243	271	299	327	355	383	411	439	467	495	523
1125	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	90	115	143	171	199	227	255	283	311	339	367	395	423	451	479	507
1150	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	99	127	155	183	211	239	267	295	323	351	379	407	435	463	491
1175	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	90	112	140	168	196	224	252	280	308	336	364	392	420	448	476
1200	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	96	124	152	180	208	236	264	292	320	348	376	404	432	460	
1225	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	108	136	164	192	220	248	276	304	332	360	388	416	444	
1250	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	93	121	149	177	205	233	261	289	317	345	373	401	429	
1275	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	105	133	161	189	217	245	273	301	329	357	385	413	
1300	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	90	90	90	90	90	90	90	118	146	174	202	230	258	286	314	342	370	398	

ANNEX 2

TRAFFIC SIGNAL INDICATIONS FOR LEFT-TURN PHASING ALTERNATIVES

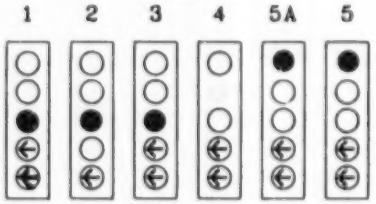
Exhibit 1
TRAFFIC SIGNAL INDICATIONS
FOR
PROTECTED PERMISSIVE
ADVANCED
LEFT-TURN PHASING

ADVANCED GREEN- A protected left turn, during which all traffic on the principal approach may enter the intersection, is provided and is followed by permissive left turns during an interval in which all traffic on the principal approach and in the opposing direction is permitted to enter the intersection.

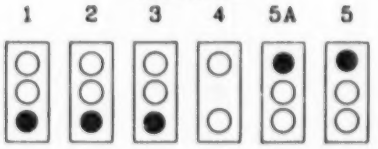
* The PRINCIPAL APPROACH is the street approach which is favoured with a signal phase to accomodate a left-turn movement.

PRINCIPAL APPROACH *

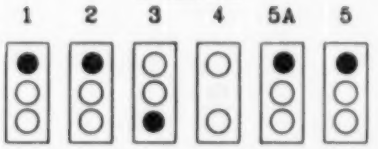
SIGNAL HEADS
GOVERNING LEFT-TURN
LANE ONLY.



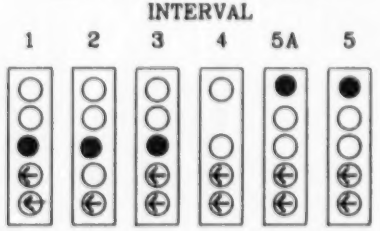
SIGNAL HEADS
GOVERNING OTHER
THAN LEFT-TURN LANES



OPPOSITE PRINCIPAL APPROACH



SHARED SIGNAL HEADS



5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

Exhibit 2

TRAFFIC SIGNAL INDICATIONS FOR PERMISSIVE PROTECTED EXTENDED LEFT-TURN PHASING

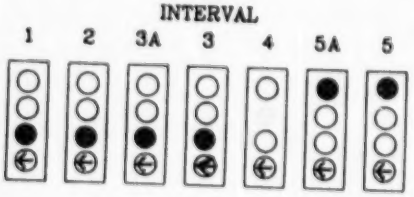
• The PRINCIPAL APPROACH is the street approach which is favoured with a signal phase to accomodate a left-turn movement.

NOTE: This phasing alternative should NOT be used where the opposing left-turn movement is allowed.

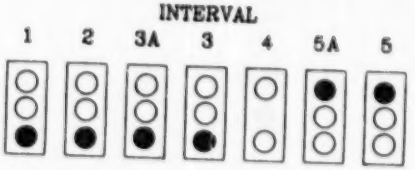
EXTENDED GREEN- Permissive left turns are allowed during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection, followed by an interval with a protected left turn during which all traffic on the principal approach only may enter the intersection.

PRINCIPAL APPROACH •

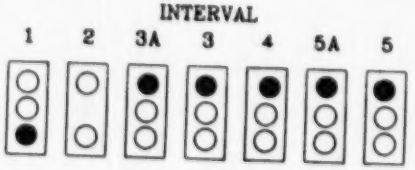
SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.



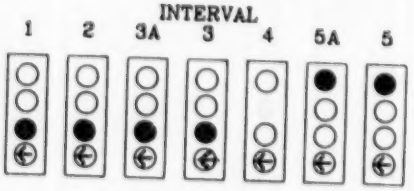
SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES



OPPOSITE PRINCIPAL APPROACH



SHARED SIGNAL HEADS



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

Exhibit 3

TRAFFIC SIGNAL INDICATIONS
FOR
PROTECTED PERMISSIVE
LEADING SIMULTANEOUS
LEFT-TURN PHASING

* BOTH APPROACHES are favoured with a concurrent signal phase to accomodate a left-turn movement.

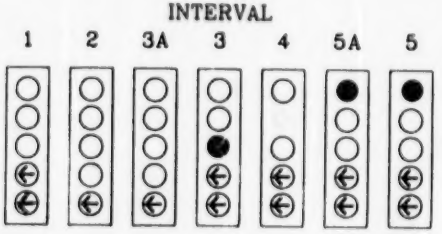
Subject to the following, both approaches will have identical signal indications.

When the left-turn phase is actuated and one of the opposing left-turn phases is not "called", the signal indications would be the same as for the protected/ permissive advanced left-turn phasing (see Exhibit 1).

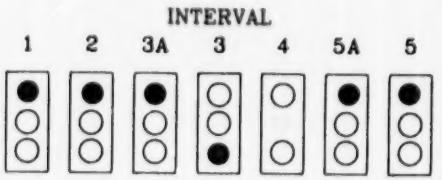
LEADING SIMULTANEOUS LEFT TURN- A protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is followed by permissive left turns during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection.

BOTH APPROACHES *

SIGNAL HEADS
GOVERNING LEFT-TURN
LANE ONLY.



SIGNAL HEADS
GOVERNING OTHER
THAN LEFT-TURN LANES



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

SHARED SIGNAL HEADS

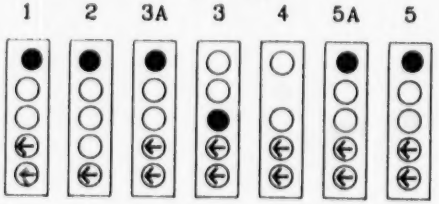


Exhibit 4

TRAFFIC SIGNAL INDICATIONS FOR PERMISSIVE PROTECTED LAGGING SIMULTANEOUS LEFT-TURN PHASING

* BOTH APPROACHES are favoured with a concurrent signal phase to accomodate a left-turn movement.

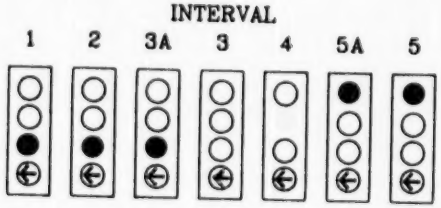
Subject to the following, both approaches will have identical signal indications.

When the left-turn phase is actuated and one of the opposing left-turn phases is not "called", the signal indications would be the same as for the permissive/ protected extended left-turn phasing (see Exhibit 2).

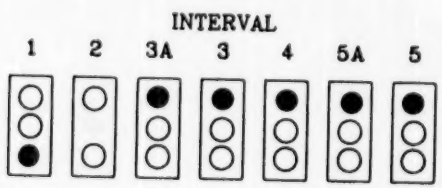
LAGGING SIMULTANEOUS LEFT TURNS- Permissive left turns may be made during an interval in which all traffic in the same direction and in the opposing direction is permitted to enter the intersection followed by an interval during which protected simultaneous left turns may enter the intersection from opposing approaches.

BOTH APPROACHES *

SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.



SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

SHARED SIGNAL HEADS

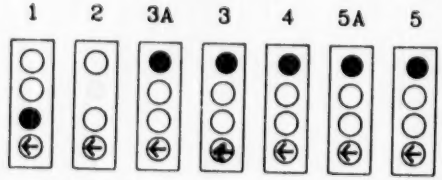


Exhibit 5

TRAFFIC SIGNAL INDICATIONS
FOR
EXCLUSIVE PROTECTED
LEADING SIMULTANEOUS
LEFT TURN PHASING

* BOTH APPROACHES are favoured with a concurrent signal phase to accomodate a left-turn movement.

Subject to the following, both approaches will have identical signal indications.

When the left-turn phase is actuated and one of the opposing left-turn phases is not "called", the signal indications would be the same as for the exclusive/ protected advanced left-turn phasing (see Exhibit 7).

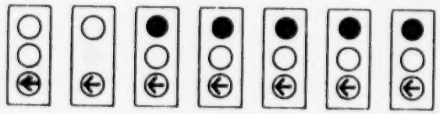
LEADING EXCLUSIVE PROTECTED LEFT TURN- A protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is followed by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

BOTH APPROACHES *

SIGNAL HEADS
GOVERNING LEFT-TURN
LANE ONLY.

INTERVAL

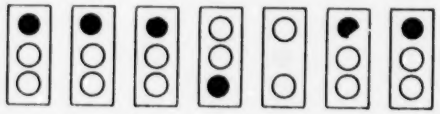
1 2 3A 3 4 5A 5



SIGNAL HEADS
GOVERNING OTHER
THAN LEFT-TURN LANES

INTERVAL

1 2 3A 3 4 5A 5



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

OPTION

SIGNAL HEADS
GOVERNING OTHER
THAN LEFT-TURN LANES

INTERVAL

1 2 3A 3 4 5A 5

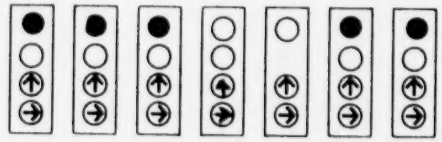


Exhibit 6

TRAFFIC SIGNAL INDICATIONS FOR EXCLUSIVE PROTECTIVE LAGGING SIMULTANEOUS LEFT-TURN PHASING

LAGGING EXCLUSIVE PROTECTED LEFT TURN- A protected left turn, for traffic from opposing directions entering the intersection simultaneously, is provided and is preceded by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

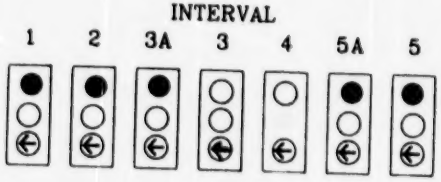
* BOTH APPROACHES are favoured with a concurrent signal phase to accomodate a left-turn movement.

Subject to the following, both approaches will have identical signal indications.

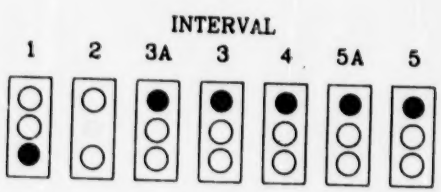
When the left-turn phase is actuated and one of the opposing left-turn phases is not "called", the signal indications would be the same as for the exclusive/ protected extended left-turn phasing (see Exhibit 8).

BOTH APPROACHES *

SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.



SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

OPTION

SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES

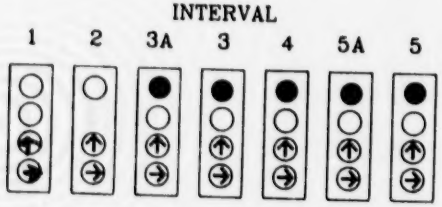


Exhibit 7

TRAFFIC SIGNAL INDICATIONS FOR EXCLUSIVE PROTECTED ADVANCED LEFT-TURN PHASING

* The PRINCIPAL APPROACH is the street approach which is favoured with a signal phase to accomodate a left-turn movement.

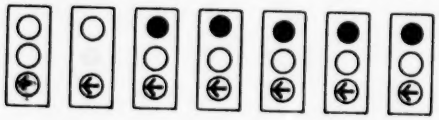
ADVANCED EXCLUSIVE PROTECTED LEFT TURN- A protected left turn, for traffic entering the intersection from one approach only, is provided while allowing concurrent through and right-turning traffic on the same approach and is followed by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

PRINCIPAL APPROACH *

SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.

INTERVAL

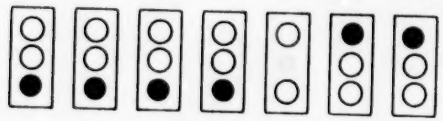
1 2 3A 3 4 5A 5



SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES

INTERVAL

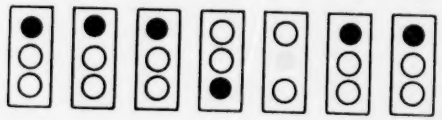
1 2 3A 3 4 5A 5



OPPOSITE PRINCIPAL APPROACH

INTERVAL

1 2 3A 3 4 5A 5



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

OPTION

SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES

INTERVAL

1 2 3A 3 4 5A 5

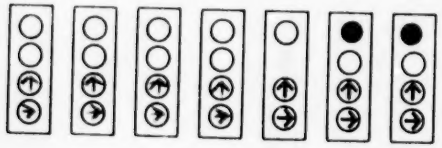


Exhibit 8

TRAFFIC SIGNAL INDICATIONS FOR EXCLUSIVE PROTECTED EXTENDED LEFT-TURN PHASING

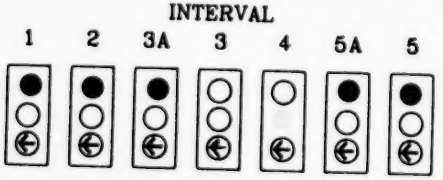
* The PRINCIPAL APPROACH is the street approach which is favoured with a signal phase to accomodate a left-turn movement.

NOTE: This phasing alternative should NOT be used where the opposing left-turn movement is allowed.

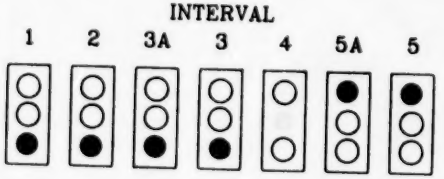
EXTENDED EXCLUSIVE PROTECTED LEFT TURN- A protected left turn, for traffic entering the intersection from one approach only, is provided while allowing concurrent through and right-turning traffic on the same approach and is preceded by an interval in which other traffic, excluding left turns, in the same direction and in the opposing direction is permitted to enter the intersection.

PRINCIPAL APPROACH *

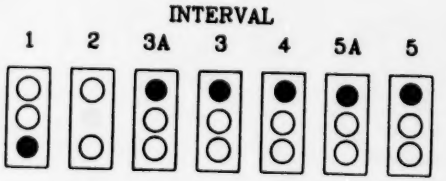
SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.



SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES



OPPOSITE PRINCIPAL APPROACH



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

5A is an optional interval which, if used, would be the "all red" portion of the change interval.

Interval 5 would normally be the green for the cross street approach.

OPTION

SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES

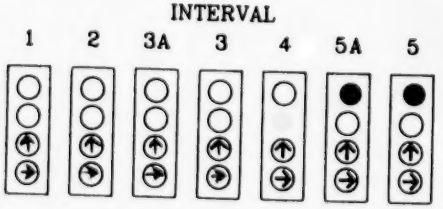


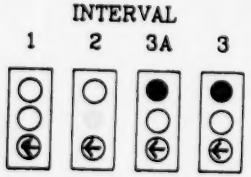
Exhibit 9
TRAFFIC SIGNAL INDICATIONS
FOR
SEPARATE PROTECTED
LEFT-TURN PHASING

* The PRINCIPAL APPROACH is the street approach which is favoured with a signal phase to accomodate a left-turn movement.

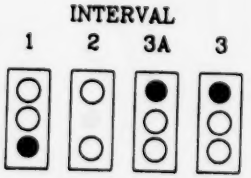
SEPARATE PROTECTED LEFT TURN- All traffic, including the left turns, is directed to enter the intersection from one approach at a time while the traffic on all other approaches is stopped.

PRINCIPAL APPROACH *

SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.

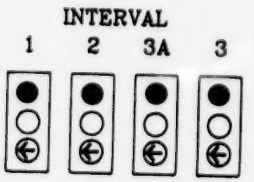


SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES

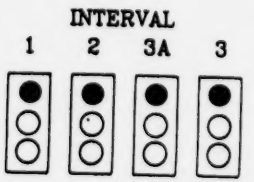


ALL OTHER APPROACHES

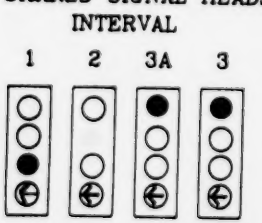
SIGNAL HEADS GOVERNING LEFT-TURN LANE ONLY.



SIGNAL HEADS GOVERNING OTHER THAN LEFT-TURN LANES



SHARED SIGNAL HEADS



3A is an optional interval which, if used, would provide for a form of the "all red" clearance portion of the change interval.

SHARED SIGNAL HEADS